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ELECTRICAL HARNESS SYSTEM DEVELOPMENT FINAL REPORT

U.S. ARMY TANK-AUTOMOTIVE COMMAND LABORATORIES

1968 November

by Fred J. Caterina

TACOM

FMC CORPORATION SAN JOSE, CALIFORNIA

U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan

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Final Report

By

Fred J. Caterina
Senior Electrical Engineer

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U. S. ARMY TANK-AUTOMOTIVE COMMAND
Warren, Michigan

CONTRACT NO. DA-04-200-AMC-2114(T)

FMC CORPORATION
ORDNANCE ENGINEERING DIVISION
San Jose, California

ABSTRACT

Under Army Contract Number DA-04-200-AMC-2114(T), a study and development program was conducted, aimed at developing the most suitable electrical harness system for military vehicles. This program, which is covered in this report, began with a broad investigation of deficiencies in present systems, the needs of future systems, and the methods and materials by which these deficiencies could be corrected and needs met. A cost analysis was conducted to determine the economic feasibility of applying these methods and materials.

The study portion of the program was followed by the preparation of a detailed system design based on the results of the study, the fabrication of a breadboard model of the system, and extensive testing of the system. The testing included both laboratory tests of system concepts and components, and field tests with the harness system installed in a vehicle.

The program concluded with the production of eight complete systems for use in the M113A1 APC and the preparation of a drawing for guidance in designing harness systems for other vehicles based on the concepts developed in this program.

The result of this program is a harness system superior to present systems, and immediately applicable because only existing military and commercial hardware was used. The opportunity for further improvements exist, delayed only by the need for additional development beyond the scope of this program. Recommendations for development efforts aimed at specific goals are included in this report.

FOREWORD

Authorization for this program was Army Contract Number DA-04-200-AMC-2114 (T) issued by the U. S. Army Tank-Automotive Command, Warren, Michigan. This is the final report on this program and represents the completion of the contract requirements.

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SECTION 1

BACKGROUND

1.1 INTRODUCTION

For many years the methods, materials and components used in the design and fabrication of military vehicle electrical harnesses have remained virtually unchanged. In other areas, particularly in the commercial and passenger vehicle field, many advancements have been made in the methods and materials used in the production and installation of electrical systems.

To investigate the applicability of advanced techniques to electrical harness systems in military vehicles, the U. S. Army Tank-Automotive Command in 1964 issued a request for proposals for a comprehensive study and development program. In reply to this RFP, and to a subsequent RFP issued the following year, the Ordnance Division (now Ordnance Engineering Division) of FMC Corporation submitted a proposal to conduct a broad study of all aspects of vehicle wiring systems: to design build and test a breadboard model of an improved system; and to fabricate a limited number of complete systems. As a result of this proposal, in February 1966, FMC was awarded a contract to conduct the program.

This document is a final report covering the purposes and goals of the program; the efforts and accomplishments of the program; and finally, the results, conclusions and recommendations stemming from the program.

1.2 PURPOSE

The purposes of the program, as defined in the contract and the amendments thereto, were to conduct a broad study of all aspects of vehicle harness systems; to develop an improved system for immediate use; and to project changes, improvements and recommended developments for future use. In order to accomplish these goals the program was divided into four phases, each of which covered specific program tasks, as follows:

- PHASE I

  (1) Conduct a broad technical analysis of electrical harness system requirements, components available now or in the future, and methods and materials for use in fabrication of harness systems.

  (2) Develop concepts for an improved harness system aimed at providing the most compact, economical, reliable and durable system possible, based on an evaluation of the study noted above.

  (3) Prepare a cost analysis of an electrical harness system for a high-production vehicle and for a low-production vehicle, including a comparison of costs for existing harness systems and costs for a system based on concepts developed in this program.

- PHASE II

  (1) Prepare a detailed design of a vehicle harness system based on the results of Phase I.

  (2) Redesign a vehicle instrument panel to assure compatibility with the harness system design.

- PHASE III

  (1) Fabricate a breadboard harness system, including instrument panel, using the detailed design developed in Phase II.

  (2) Perform laboratory tests on the breadboard system to assure that the requirements of the system are met.

- PHASE IV

  (1) Install the breadboard harness system in a vehicle and conduct a test program on the system while in actual operation.

  (2) Fabricate eight (8) complete harness systems, including instrument panels, incorporating design modifications deemed advisable as a result of the test program.

  (3) Prepare a typical harness system drawing for use by ATAC as a sample drawing in the preparation of future harness system designs.

A detailed treatment of the steps taken and procedures used to accomplish these aims is presented in Section 2 of this report.

SECTION 2

PROGRAM

2.1 PROGRAM PHASE I - ENGINEERING STUDY

A complete and detailed report of the activities and results of this phase of the program is given in FMC Corporation report entitled "Electrical Harness System Development - Phase I Engineering Study" (1) A summary of that report is presented herein.

2.1.1 Technical Analysis

In order to establish a basis from which a harness improvement effort could evolve, it was necessary, at the outset, to determine the following four items:

- First, areas where immediate improvement was a requirement, based on deficiencies in existing installations
- Second, improvements or changes which would become necessary in the future, due to changing requirements of vehicle electrical systems
- Third, the components and materials available, now and in the future, with which to effect the required improvements
- Fourth, the design techniques by which improvement may be realized

The first step, the determination of deficiencies in present harness systems, was accomplished by an extensive survey of persons associated with the design, fabrication, installation, use, and maintenance of vehicle electrical harness systems. This included interviews of military and civilian personnel at Tooele Army Depot, Utah, and Fort Ord, California, as well as with key personnel at FMC associated with engineering, manufacture and field service functions. Discussions were also held with personnel at the General Motors assembly plant in Fremont, California and the Ford Motor Company assembly plant in Milpitas, California to ascertain problem areas in commercial vehicle harness systems. In addition to these personal contacts, field service records of FMC Corporation were studied for evidence of major harness system deficiencies. A list of major problems is as follows:

- Deterioration of wire insulation
- Electrically oversize conductors required for mechanical strength
- Difficulties and high cost incurred in tape wrapping of harnesses, and poor mechanical protection of wires given by tape wrapping
- Troubles encountered in manufacturing and troubleshooting spliced circuits in harness bundles
- High cost and poor repairability of molded splice covers and wire breakouts
- Quality control difficulties encountered with soldered connector contacts
- Lack of test points with which to make electrical tests on an energized system

- Lack of adequate engineering effort in harness system design - prototype systems become frozen into the final design

- Harness locations given minimum accessibility to connections and minimum protection from oil and moisture.

A projection of future harness system change requirements was made, based on an analysis of trends in vehicle electrical systems. Electrical system changes which will have to be accommodated by the harness systems of the future will include the following:

- Higher voltage systems - electrical requirements of the Main Battle Tank, the LVTPX12 (Marine Corps) and the projected MICV-70 have pressed 24-volt generating and distribution systems near their practical limits.

- Alternating-current systems - advances in power-conversion systems and increasing requirements for AC power may bring about more direct use of alternating current in military vehicles.

- Extended use of electronics in vehicles will probably result in extended use of shielded circuitry.

It appears that any harness system components available now or in the near future for use on 28-volt DC systems would be adequate for any electrical system characteristics that could reasonably be expected to be used in vehicles for many years. Specifically, voltages up to 120 volts, either DC or AC up to 400 Hz, would not require changes in electrical harness methods, although safety precautions normal to the particular voltage in use would have to be taken. This would include door interlock switches on panels, warning plates and other precautions to avoid electrical shock hazard to personnel. Special shielding requirements will have to be accommodated as necessary.

After the foregoing specific improvement needs were established, an extensive industry survey was conducted to determine the availability of components and materials suitable for the application. An "Industrial Survey" letter and questionnaires were sent out to approximately 775 manufacturers of harnessing and related components between March 10 and March 18, 1966. A separate questionnaire for each category in which a vendor might deal was sent to the vendor. A card file was established, showing all vendors contacted and for which categories. As questionnaires were returned, notations were made in the card file showing that a reponse was obtained and the nature of the response (enthusiastic, negative, etc.).

The questionnaire and any catalog or data sheets were then filed alphabetically under the category of the item manufactured. These categories are:

Cable Assemblies

Flat Cable

Multiconductor Cable

Power Cable

Bus Bars and Systems

Cable and Wire Clamps, Clips and Ties

Conduit

Tubing

Connectors

Terminals, Strips and Blocks

Adhesives

Potting Compounds

Many of the more interested manufacturers provided samples of their products for our investigation and consideration. It was decided that these samples should be turned over to USATACOM, where they could be seen by anyone interested in this harnessing study. For convenience, they were mounted on three wooden display boards suitable for hanging on the wall. Each sample item was numbered, and a few specific comments and vendor data concerning each were included under the corresponding number in an accompanying notebook. A photograph of each of these boards is presented in Figures 1, 2, and 3.

It is recognized that many of these are samples of items not fit for military use in their present form. They do show, however, the trend in commercial products in methods and materials, and with slight adaptation or improvement may be convertible into a military version. Thus they were included to stir the imagination of the interested parties.

The remaining item that required investigation was the use of different design techniques and system configurations to achieve various improvements. A number of techniques were investigated for improving reliability, maintainability, and economy in harnesses. Many of these were found to be of distinct value and were subsequently incorporated in preliminary concepts, the breadboard harness system, and in the final production units. These will be covered in later sections of this report when the various harness systems are discussed, but several distinct items are covered in detail below.

2.1.1.1 Static Switching Study

A study of the use of static switching for electrical circuits in military vehicles was specifically required by the contract. The potentials of static switching over electromechanical switching devices are:

- Resistance to shock and vibration
- High reliability
- Long life
- Fast switching capability
- Lower radio interference in many applications

The advantages are being utilized in certain components, such as voltage regulators and inverters which have been converted to completely solid-state units.

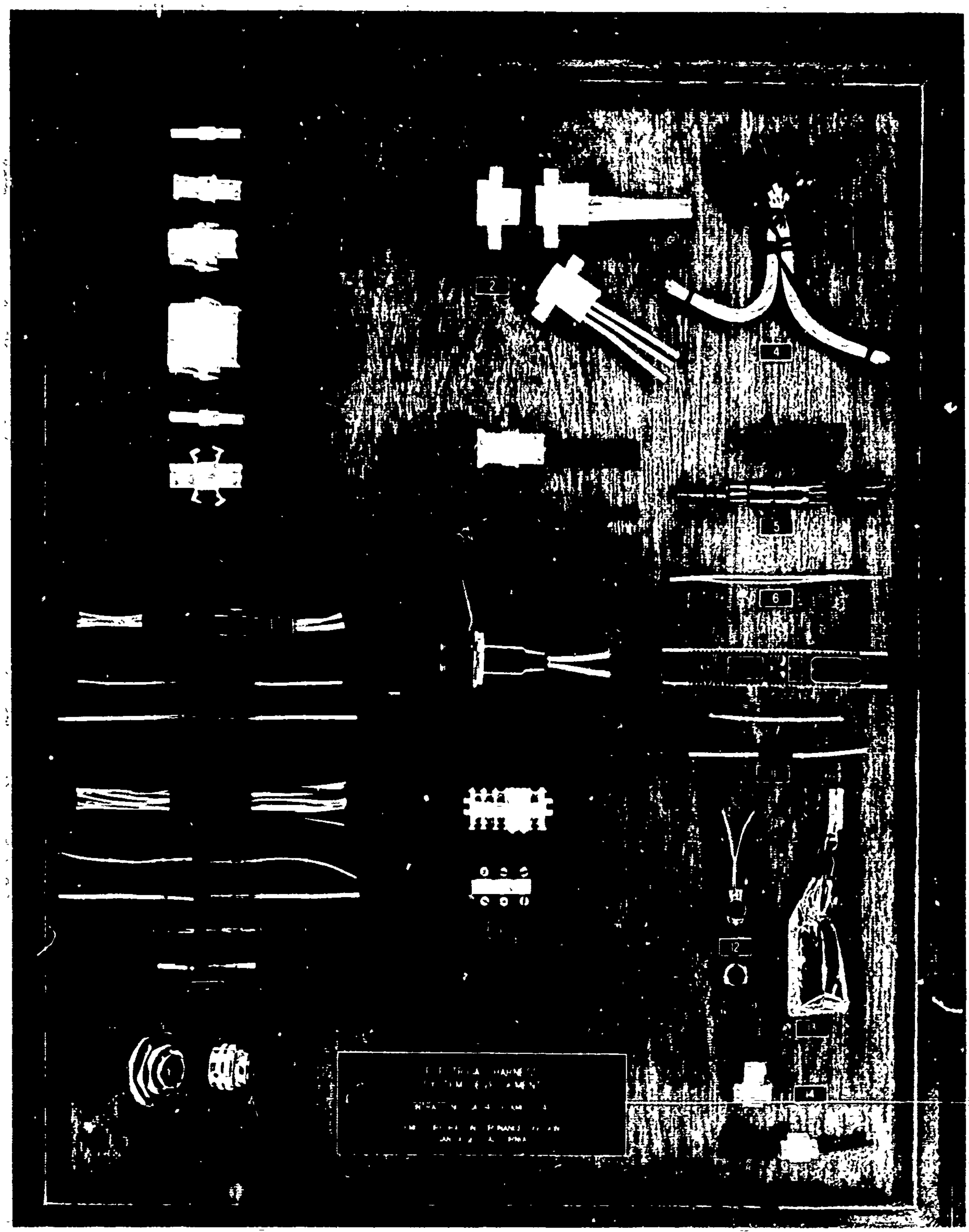

FIGURE 1 ELECTRICAL HARNESS COMPONENT SAMPLES

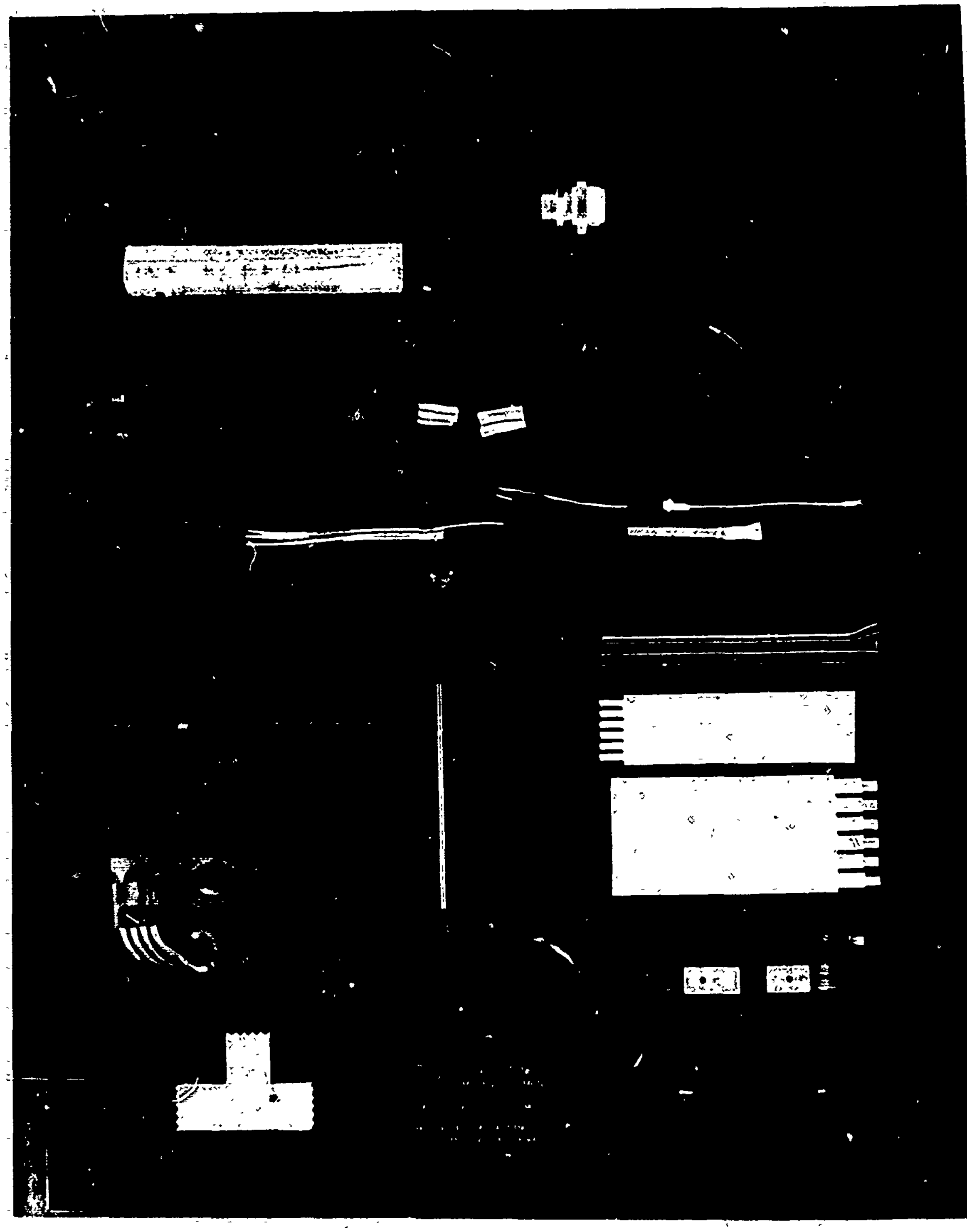

FIGURE 2 ELECTRICAL HARNESS COMPONENT SAMPLES

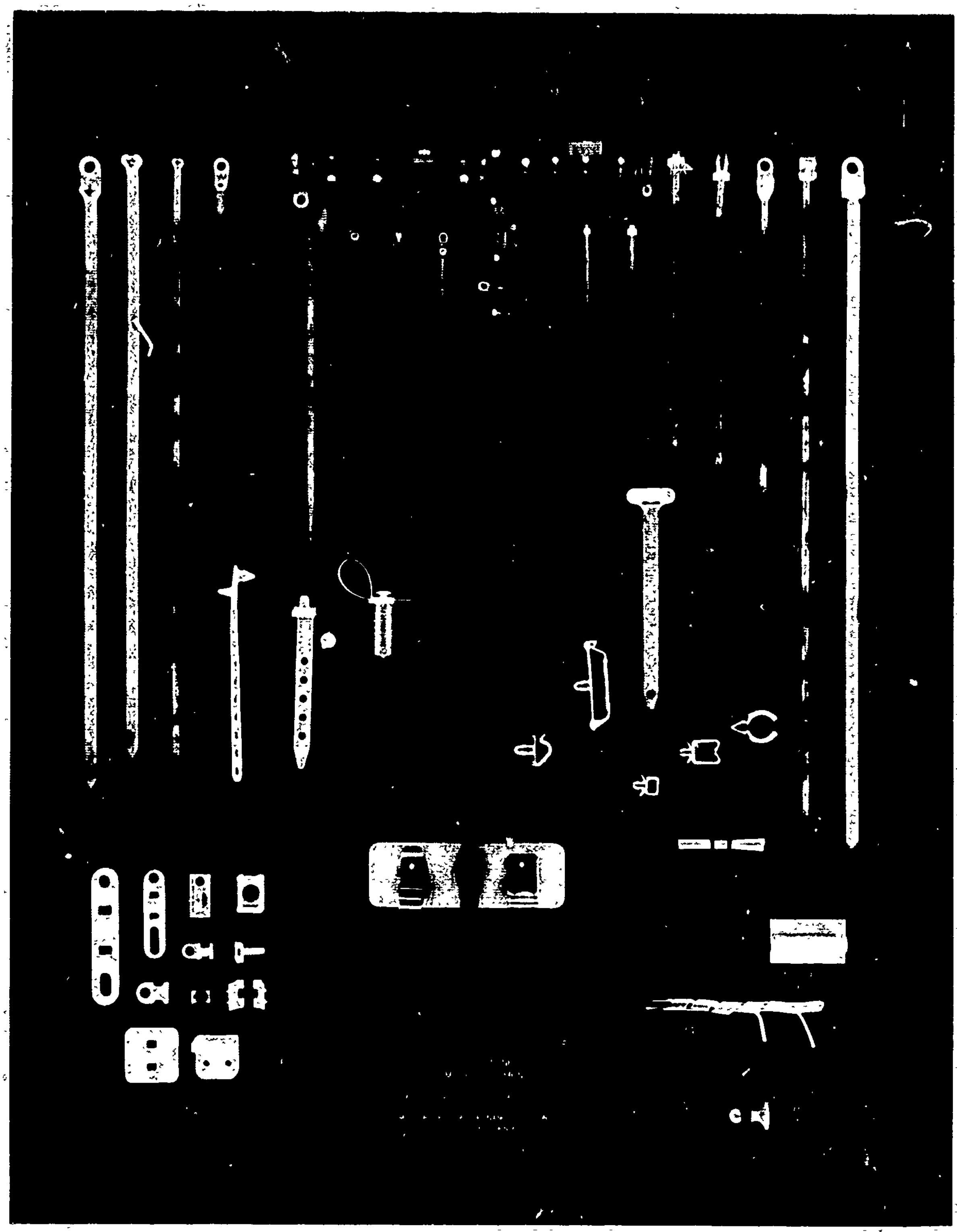

FIGURE 3 ELECTRICAL HARNESS COMPONENT SAMPLES

More universal use of static switches to replace common toggle switches, relays, and contactors has been slow to come about for several reasons. First, the fast switching capability is of no great value in these applications. The switching time of mechanical contacts is usually fast enough for the loads involved. Secondly, static switches available at the moment have several disadvantages:

- An inherent voltage drop is produced across the contact. In most applications this voltage drop would not cause any problem at the load. If design requires that the load current pass through a number of contacts in series, the total voltage drop in all contacts may be unacceptable to the system, particularly in low-voltage systems, where a comparitively small absolute value of voltage may be a substantial percentage of the system voltage.

- The voltage drop mentioned above generates heat within the static switch, which must be dissipated in some manner.

- Solid-state devices used in a static switch have upper and lower operating temperature limitations which are usually more severe than those placed on the mechanical counterparts. The internally generated heat mentioned above aggravates the condition and lowers the upper ambient temperature in which the device can be operated, which usually results in the upper temperature limit being a more severe restriction in usage than the lower limits.

- Solid-state devices are susceptible to damage caused by voltage transients in the circuit. Since vehicle systems are generally apt to generate such transients, static switches must be designed with built-in protective circuitry, thus adding to the cost and subtracting from the reliability.

- The present cost of solid-state devices which will withstand the vehicle environment is high compared to the cost of the electromechanical component which it replaces.

A detailed study concerning the use of static switching in aircraft electrical systems was conducted by the Chance Vought Corporation under Navy Bureau of Weapons Contract NOw 62-0944-C. This study, "Investigation of Contactless Switching Concepts for Application to Aircraft Electrical Systems," (2) is, in the most part, applicable also to military vehicle systems. One of the study's conclusions is: "To replace existing electromechanical relays and circuit breakers with solid-state relays and circuit breakers obviously is not practical. The overall contact voltage drop would be unacceptable in the d. c. system since power to some loads is supplied through a series of relay contacts. The resulting system size and weight would also be prohibitive since static relays and circuit breakers are much larger and heavier than their electromechanical equivalent."

In view of the foregoing, the use of static switching has not been considered in the development, in this program, of harness concepts for immediate or near-future use. However, the rapid advances being made in solid-state electronics suggest that the applicability of these devices should be investigated at frequent intervals.

2.1.1.2 Test and Checkout Considerations

A consideration of the need for adequate means to test and check out a vehicle electrical system necessitated a detailed study of harness termination methods. This results from the

fact that today's harnesses make testing difficult due to internal splices and lack of available test points when the harness is installed and connected. Tests on a partially disconnected system frequently preclude testing with the system energized, thus limiting test capability.

In terminating wires at a piece of equipment, some sort of connection is obviously required, and the only question is that of connection type.

External Wire-to-Connector-to-Internal Wire-to-Electrical Component

External Wire-to-Terminal Bd. -to-Internal Wire-to-Electrical Component

External Wire-to-Splice-to-Internal Wire-to-Electrical Component

External Wire - Direct to electrical component

Normally, the choice of which of these four methods to use is dependent upon the equipment design, installation requirements (accessibility, degree of exposure to water, etc) complexity, and servicing requirements. Equipment subject to periodic removal for servicing (e.g., a voltage regulator) or mounted in a location making other types of termination difficult (e.g., an alternator) normally would be furnished with connectors. On the other hand, equipment such as instrument panels are normally in comparatively accessible locations, and servicing requirements are related to individual components rather than to the unit as a whole, making them very adaptable to wire termination direct to components, or through terminal blocks. The present custom of open-back instrument panels, taken together with the need for watertight integrity, has precluded the use of terminal strips and has resulted instead in a myriad of Packard connectors, Ordnance (multipin) connectors and pigtailed wires from individually watertight components. The proposed modification in this area is to provide watertight integrity to the unit as a whole by use of an enclosed rather than an open panel, with components sealed only at their interface with panel cutouts. Wire terminations will be made at terminal boards with cables entering the enclosure through grommetted holes, or, for vehicles requiring fording capability, through watertight stuffing tubes.

2.1.1.3 Harness Terminations

As a corollary to the previous item, a study of multipin connectors was made to determine the types most suitable for use in military vehicles. The large grommet holes of Ordnance-type connectors per Drawing No. 7723494 are suitable only for large-diameter wires such as the low-voltage wire covered by MIL-C-13486. Conversely, the use of this type wire has to a large degree necessitated the continued use of the Ordnance connector. Just as the use of these two items went hand in hand, so too the discontinuance of one would require abandonment or modification of the other. From the program's inception, it appeared that a recommended replacement for MIL-C-13486 wire would be a key result and, since almost all high-quality insulation wires available today have a much smaller diameter (possible exceptions are silicone rubber and hypalon), a thorough consideration of multipin connector types was necessary. In addition, the contemplated use of jacketed multiconductor cable necessitated a connector in which a cable jacket could be internally terminated, and environmental sealing provided between the jacket and the connector.

The result of the study was that the most practical units for immediate general use are those built per MIL-C-5015, Class R with crimp-type, in lieu of solder-well type contacts. Crimp-type contacts are not currently covered by the specification, but information from several connector manufacturers indicates that a revision is either contemplated, or in process, to include this alternative. There are several reasons for this choice. First,

they will mate with existing Ordnance-type connectors (Drawing No. 7723494), allowing an orderly transition in connector usage. Second, they have the most widespread usage of any military connector, not only in all of the military services but in a great many commercial applications as well. This wide-spread usage favorably affects both cost and availability. Third, many items of electrical equipment used in military vehicles are equipped with receptacles made per this specification, thus no problems would be encountered in logistics of replacement parts. Fourth, most common wire types have diameters compatible with the grommet hole sizes. Fifth, adapters are readily available for terminating cable jackets internally and sealing with an MS3057B cable clamp. Sixth, the quality control possible with crimp-type contacts increases the reliability of connections by elimination of cold solder joints and carbonization of inserts from overheating.

The main disadvantage of the MS connectors per MIL-C-5015 as compared to the Ordnance type is that the MS types are less rugged and cannot be exposed to the degree of rough usage that the Ordnance types can. In addition, the Ordnance-type plugs are somewhat shorter than the MS types.

Nonmilitary types were examined for features applicable to military vehicles, and some were later included in the breadboard harness system for demonstration and test purposes. Although none were really suitable for vehicular use at this time, the manufacturers were encouraged to develop adaptations for military environments.

Several of the attractive possibilities are listed below, with the advantages they offer:

- Modular Construction - useful for direct transposition from multiconductor cable to single or smaller-sized multiconductor cable, eliminating junction box in a multiconductor wiring scheme.

- Flat-to-Round Adaptors - would permit flexible, advantageous use of flat and round multiconductor cables. Also, might permit junction box elimination by use of "peel-off" capabilities of flat cable.

- Flat Cable Connectors - availability of waterproof units is required before complete flexibility in application of flat cable can be achieved.

2.1.1.4 Harness Configuration

The modern concept of replacement in lieu of repair as a field maintenance technique required a careful analysis of system configuration. Present harness configuration, in which a large percentage of the system comprises one large multibranched assembly, precluded replacement of harness sections except on an almost all-or-nothing basis. In lieu of this, a segmented configuration highly compatible with the harness termination proposals noted above, was developed. This configuration was carried throughout the program, and forms the basis of the new harness system.

2.1.2 Harness Concepts

The next task in the program was to apply the results of the engineering study to the development of concepts for improved harness systems. In order to provide a realistic basis for these concepts, they were developed for two existing military vehicles. Four alternate concepts were developed for the medium-production M113 APC, and two concepts developed for the high-production, but electrically simpler, M151 truck (jeep).

The changes incorporated in the alternate harnesses may be divided into two groups:

(1) Use of materials and components not presently used.

(2) Harness design features and concepts not presently used.

Those changes falling in the first category are, generally speaking, similar for all the alternates included, and are as follows:

- Use of multiconductor cable (with or without breakouts)
- Use of flat cable (M151 alternate No. 1 only)
- Use of crimp-pin type connectors in lieu of soldered pins
- Use of improved wire insulating and jacketing material not requiring further physical protection by tape wrapping or sleeving
- Use of nylon ties in lieu of spot taping for wire bundle retention where use of multiconductor cable is impractical
- Use of nylon ties in lieu of adel clamps for affixing cable or wire bundle to vehicle structure.
- Use of panel components, such as switches, indicator lights, etc., having screw-type wire terminals in lieu of integrally mounted packard connectors
- Use of reduced wire sizes based solely on electrical requirements.

The changes included in the second category are varied in their application to each of the alternate harnesses analyzed. These are as follows:

- Elimination of splices in harnesses by use of dual circuits or by use of intermediate junction boxes
- Use of enclosed instrument panels in lieu of open-back panels, the degree of enclosure (i.e., dripproof vs. submersible) depending on the requirements of the particular vehicle
- Consolidation of headlight, infrared light, blackout markers, blackout drive light and horn, as required, as a single subassembly, with all leads emanating from one connector
- Relocation of electrical components and equipment, not only to facilitate harnessing, but also to improve operation of the electrical system
- Minimizing, or eliminating completely, breakouts, particularly where use would necessitate molded rubber boots, heat-shrinkable breakout covers, tape wrapping, or any other method of maintaining physical integrity of harness or cable jacketing.

Drawings of each of these concepts were included in the Phase I report (1).

2.1.3 Cost Analysis

The final task in Phase I was to prepare cost analyses of the harness concepts previously developed and to compare these costs to those of the existing harness systems. The cost analyses were made using standard MTM data. For instrument panels and electrical items other than harness components, only cost increases and decreases were included. The results for these items therefore indicate cost changes rather than total costs, and only initial costs were included. That is, no attempt was made during this cost analysis to estimate cost savings over the life of the vehicle due to reduced electrical maintenance costs.

A summary of these analyses are presented in Tables I and II. For the complete analysis, including drawings, see the Phase I report (1).

TABLE I

M113 COST COMPARISON SUMMARY

	PRESENT HARNESS		ALTERNATE NO. 1		ALTERNATE NO. 2		ALTERNATE NO. 3		ALTERNATE NO. 4	
	Hours	$	Hours	$	Hours	$	Hours	$	Hours	$
LABOR										
Harness Fabrication	12.045	111.11	4.380	40.13	4.135	37.84	4.171	38.16	3.963	36.23
Panel and Headlight Assemblies (Net change over present assemblies)	---	---	1.534	14.04	1.727	15.80	2.048	18.74	2.057	18.82
Installation	8.145	74.53	7.106	65.02	7.273	66.54	7.408	67.78	6.958	63.67
Total Labor Cost		185.64		119.19		120.18		124.68		118.75
MATERIAL										
Harness		132.70		249.05		262.04		232.10		177.75
Panel and Headlight assemblies (Net change over present assemblies)		---		- 1.64		- 6.24		- 3.77		- 4.67
Total Material Cost		132.70		247.41		255.80		228.33		173.08
TOTAL COST		318.34		366.60		375.98		353.01		291.83

TABLE II

M151 COST COMPARISON SUMMARY

	PRESENT HARNESS		ALTERNATE NO. 1		ALTERNATE NO. 2	
	HOURS	$	HOURS	$	HOURS	$
HARNESS FABRICATION Labor Cost	5.335	48.82	3.347	30.63	4.427	40.51
HARNESS INSTALLATION Labor Cost	3.120	28.55	2.230	20.40	2.537	23.21
TOTAL LABOR COST	8.365	77.37	5.577	51.03	6.964	63.72
MATERIAL		15.31		61.88		40.94
TOTAL COST		92.68		112.91		104.66

2.2 PROGRAM PHASE II - HARNESS SYSTEM DETAILED DESIGN

The development of a detailed harness system design based on the Phase I studies, and the concepts which evolved from them, was the task assigned for program Phase II. Several ground rules were established to provide the framework within which this would be accomplished:

- The harness was to be designed for an actual vehicle. The M113 was chosen because of the ready availability of this vehicle at FMC for reference use during design, and also because of the extensive cost analysis effort made in Phase I on this type vehicle.

- The harness would be designed as a test system rather than as one intended for service. This meant variation instead of standardization in selection of components, permitting evaluation of a larger number of items than would otherwise have been possible. It also permitted the use of components with the aim of evaluating application concepts rather than hardware suitability.

- Redesign of the instrument panel would be limited to the physical configuration necessary to assure compatibility with the harness system. No attempt would be made to evaluate either the instrumentation functional requirements or the design of individual instruments (other than wire-termination methods).

Within tl.'s framework a complete set of drawings was prepared for the fabrication and installation of a test harness system. A list of the drawings is presented in table III.

TABLE III

LIST OF DRAWINGS FOR PROTOTYPE HARNESS SYSTEM

Drawing No.	Title
1067230	Wiring Diagram, Electrical
1067231	Electrical Installation
1067232	Panel Box Assembly
1067233	Panel Box
1067234	Bus Bar
1067235	Bracket, Indicator
1067236	Spacer, Support
1067237	Spacer, Support
1067238	Junction Box, Electrical, Rear
1067239	Wiring Harness
1067240	Gasket, Rubber

TABLE III (Continued)

Drawing No.	Title
1067241	Guard, Cable
1067242	Diagrammatic Layout, Vehicle, M113A1
1067243	Lead, Electrical
1067244	Gasket, Rubber

A brief description of the key features of the major drawings follows:

Drawing No. 1067242, Diagrammatic Layout, Vehicle, M113A1 is a key plan showing the system configuration, relationship of component portions of the system and relative location of harness system components and electrical equipment in the vehicle.

Drawing No. 1067232, Panel Box Assembly, is the assembly drawing of the enclosed instrument panel which will replace the open-back instrument panel now in use. The instrument-panel design incorporates several design features not found in the present panels.

- The instrument panel combines the functions of the present instrument panel, indicator light panel and junction box, thereby simplifying the manufacture, installation, component interconnection, and maintenance of the panel and its component devices.

- The use of an enclosed panel permits the use of standard panel components. The degree of environmental sealing required, which may vary with different vehicles, is provided by the panel enclosure. In the M113 system, the required degree of tightness is less than it would be in a fording vehicle, and grommets for cable entrances and gasketed covers were provided for dripproofing and moisture sealing.

- Terminals boards, accessible by opening the hinged front cover of the panel, permit testing or troubleshooting the electrical system with the system energized and fully connected.

  NOTE: Several different types of terminal boards were used in this box. As noted above, this was done only for demonstration purposes and was not intended to indicate such an approach for an actual service harness.

- The use of an enclosed panel with internal terminal boards permits the elimination of connectors, by direct entry of cables into the panel. This concept would permit the elimination of Packard connectors on the individual meters, switches and indicator lights, and the Ordnance connector on the lighting switch. This was done for the toggle switches and indicator lights by the simple expedient of using non-Ordnance units. For the meters and lighting switch, Ordnance units had to be used and, since it was not within the scope of this program to redesign instruments, these units were used with their existing connectors inside the panel. Adaptation for general use of the harness system developed in this program would obviously warrant redesign of these instruments.

Two connectors for termination of harness sections were incorporated in the design of the panel for the purpose of demonstrating the application of commercial connector types in vehicles.

The mechanically driven indicators, i.e., the speedometer and tachometer, were mounted on a bracket, Drawing No. 1067235, which was attached externally to the operator's panel. This design permitted grouping the instruments together for maximum operating convenience while eliminating the problem of installing mechanical drive cables to the hinged front panel of the operator's panel box. Because of the mounting location of the panel in the M113, off the driver's left side, better instrument visibility was provided by designing the bracket so that the face of it forms an angle with the panel-box face. This arrangement is shown on the installation drawing No. 1067231.

Drawing No. 1067239, Wiring Harness, details the construction of each individual harness section. The various sections demonstrate several different methods of harness design and fabrication. Conductor assemblies included ribbon-type multiconductor cable, round jacketed multiconductor cable, bundles of individual wires assembled with nylon ties, and single conductors. Each of these types of conductor assemblies has distinct potential advantages, with the choice dependent on breakout requirements, termination requirements, type of service, location in vehicle and installation considerations. As in the operator's panel, an attempt was made in designing the harness to demonstrate the application of a variety of methods and materials. Cable and conductor terminations included terminals designed for use with the diverse terminal block types and nylon connectors installed in the operator's panel, as previously noted. Cylindrical connectors required to mate with ordnance or MIL-C-5015 receptacles and connectors were identical to the MIL-C-5015 Class R connectors, except that crimp-type pins and sockets were used in lieu of the soldered type and that, where required, a backshell adapter was provided for cable sealing. The trailer receptacle also had crimped sockets and backshell adaptor.

In fabrication, the harness design offers the advantages of adaptability to the high-speed and quality control capabilities of automatic machinery such as cable cutters, wire strippers and terminal crimpers. Splices, soldered connections and tape wrapping, all time-consuming manual operations with difficult quality control characteristics, have been entirely eliminated. The design of the harness system in individual sections affords ease of handling during initial installation, and the capability of replacing small sections in case of damage, rather than complete harnesses or major sections. The use of high temperature Kynar insulation on engine compartment harness sections permits the elimination of fiberglass sleeving currently used as an outer protection in this area.

Drawing No. 1067231, Electrical Installation, shows the precise location of each component in the vehicle, along with installation hardware and materials. The sectional construction of the harness made possible the elimination of connector plugs and receptacles for bulkhead penetrations into the engine compartment, and the use of relatively inexpensive nylon stuffing-tubes instead.

Nylon ties, similar to those used for tying wire bundles, were utilized for affixing wire bundles and round multiconductor cables to nylon pads attacked to the vehicle structure. with adhesives. The installation of harnesses using nylon ties for support is much faster than with Adel clamps, and having the harnesses closer to the bulkhead on the pads as compared to the welded studs leaves them less vulnerable to damage. Flat ribbon-cable installation was to have been made by adhesives.

Drawing No. 1067230, Wiring Diagram, Electrical, is a complete interconnection diagram of the entire system, intended for use in fabricating the components, installing the system and in troubleshooting and maintenance procedures when the system is in service.

The remaining drawings are details of parts, fittings etc., required to complete the design reviewed in the preceeding paragraphs. The completed set of drawings was submitted to ATAC for approval on 28 April 1967.

2.3 PROGRAM PHASE III - FABRICATION AND LABORATORY TESTS

A complete harness system, based on the drawings developed in Phase II, was fabricated at the start of this phase of the program. In addition to the harness itself, the system included the instrument panel, complete with all instruments, controls, circuit breakers, and other electrical components.

The system was then subjected to a series of laboratory tests to determine the suitability of components and fabrication methods used for application to military vehicle electrical systems. Appendix A of FMC report "Electric Harness System Developement - Phase III - Breadboard Harness System Fabrication and Testing" (3), presents details of the test plan, procedures used, and results obtained. A brief description of the specific goals of the test program and a summary of the results obtained follows:

2.3.1 Purpose of Tests

- To check continuity of circuits through the harness system with all harness sections connected.
- To check instrument panel circuitry by measuring resistance values with the panel deenergized, and voltage values with panel energized and control devices in various operating conditions.
- To determine the ability of the harness system to withstand degradation in dielectric strength, insulation resistance and contact resistance after exposure to severe temperature and humidity variations.
- To determine the tensile strength of various crimp-type wire terminations used in the harness system.
- To determine the bond strength, in peel and in shear, of several commercial adhesives. Also, to determine the deteriorating effect, if any, on this bond strength by exposure to moisture, motor oil, gasoline and transmission fluid.

2.3.2 Summary of Results

Harness continuity tests established the agreement between designed harness circuit connections and actual fabricated connections.

Instrument panel resistance and voltage tests, and visual checks confirmed the proper operational functioning of panel controls, as well as the correctness of panel circuitry.

The properties of dielectric strength, insulation resistance, and contact resistance of two test sections were measured per MIL-STD-202C, Methods 301, 302 and 307 respectively. The harness sections were then subjected to the environmental conditioning specified in MIL-STD-202C Method 106B (Modified). The test measurements were then repeated and the results showed no detectable degradation in these properties as a result of the subjection to vibration and environmental cycling.

Tensile tests on an assortment of crimped wire terminals were made in three groups: (1) immediately after crimping of terminals, (2) after exposure to environmental conditioning and vibration as noted above, and (3) after extended immersion in hydrocarbon fluids. All samples exceeded the tensile strength requirements of MIL-T-13513 (ORD) and MIL-T-7928E (ASG), with the exception of two specimens from the third group. These two failures occurred on Packard-type terminals.

Four commercial adhesives were tested in two types of application: (1) nylon pad bonded to aluminum with shearing stress applied, and (2) polyvinyl-chloride-insulated ribbon cable bonded to aluminum with "peeling" force applied. All tests were made in three groups; (1) immediately after bond cure, (2) after exposure to environmental conditioning and vibration as above, and (3) after extended immersion in hydrocarbon fluids. In the first application, three of the adhesives used had shear strengths exceeding the 50-pound tensile strength required by MIL-S-23190A (WEP) for the nylon ties with which the tested pads are designed to be used. They may therefore be satisfactory for use in harness installations although none were outstanding under all three test conditions. In the second application, none of the products performed well enough to be considered satisfactory for direct adhesion of PVC-insulated ribbon cable to the structure of military vehicles.

2.4 PROGRAM PHASE IV - PRODUCTION

Initially, the fourth and final phase of the harness development program was to have consisted solely of the production of a limited number of harness systems in accordance with detailed designs developed earlier in the program. By contract amendment, this was later revised to include the following three major tasks:

- Installation of the breadboard harness system in a GFE M113 and conducting an in-vehicle test program
- Production of eight (8) harness systems, including instrument panels
- Preparation of a Typical Electric Harness Drawing.

A detailed report of the accomplishments of these tasks is presented in FMC report "Electric Harness System Development - Phase IV - Production Harness System, In-Vehicle Test Program, Typical Electric Harness Drawing" (4). A summary of that report is presented herein.

2.4.1 In-Vehicle Test Program

2.4.1.1 Purpose of Tests

The purpose of this program was to install the breadboard harness system in a GFE M113 vehicle, carefully noting the suitability of installation methods and materials, and accomplishing the following specific tasks:

- Record actual installation time, and extrapolate over a normal learning curve in order to provide a basis for installation cost comparison with present installation methods.
- Determine the accessibility of individual components of the system for ease of inspection, removal and repair.
- Test voltages, with system energized, at various test points to determine the ease of checkout and test on a hot system.
- Operate the vehicle on FMC test track for approximately 160 hours over a variety of terrain. During this period, subject the harness system to deliberately excessive contact with hydrocarbon fuels and hydraulic fluids, and to simulated rainfall and daily morning condensation. Perform the following inspections and tests periodically during the track operation period:

  (1) Visual inspections for signs of physical deterioration.

  (2) Insulation resistance tests for deterioration in measured values.

  (3) Voltage drop tests to determine corrosive effects of operational environment on system contact surfaces.

  (4) Continuity tests to detect possible breaks in small-gage system conductors.

- Determine the retention of the flat-cable adhesive by measuring the force required to pull cable from bulkhead. Also, to determine the effects of thermal expansion and contraction on an adhesively installed flat cable.

2.4.1.2 Summary of Results

Installation of the harness system in the vehicle was preceded by the preparation of detailed instructions. Actual installation followed generally the prepared procedure but deviated when it seemed advisable. Modifications to the system design, both in circuitry and physical configuration, were required due to the test vehicle being a gasoline-powered vehicle instead of the diesel-engine version for which the harness system was designed. Installation methods and materials were generally very good, but several adhesive types failed. The method of penetrating the engine compartment bulkhead in one instance proved cumbersome and was redesigned for simplicity and ease of installation. Time records were kept, which later were incorporated into an installation cost analysis. Comments by installation personnel and test drivers were generally favorable to the new system. After installation, the following tasks were accomplished.

- Actual recorded installation time for the breadboard system, and projected time for installation of similar systems on a vehicle production line indicates a potential installation cost reduction of almost 20 percent as compared to present M113 harness systems (6.74 man-hours vs. 8.15 man-hours). This is in substantial agreement with the cost analysis made in Phase I of the development program and presented in detail in the Phase I report. (1).

- Examination of the installed harness system showed most portions of the system to be very easily accessible for inspection, repair-in-place, or removal for repair or replacement. Those portions of the system located in less accessible areas, as required by their service function, while not as easily inspected or repaired in place, are nonetheless fairly easy to remove for repair or replacement. This is due to the sectionalized design of the system, permitting removal of comparatively small segments of harness without disturbance to the rest of the system. The breadboard system consisted of sixteen sections, while the eight production systems consisted of fourteen sections. Panel component accessibility, particularly, is distinctly improved over present installations.

- System checkout and tests confirmed the expected capability to electrically test an energized and fully connected system. Limitations on this capability were confined to instruments and controls which were designed as sealed units for open mounting, rather than for mounting in an enclosed panel. Isolation of harness sections for continuity and insulation resistance testing was very easy at the two central junction points of the system, the instrument panel and the rear junction box.

- Vehicle operation extended over a period of two weeks, with daily examination and electrical checkout of the electrical system. During this time the harness system was subjected to hostile environmental conditions indicated in the test plan. Some excessive condensation was experienced inside the instrument panel, indicating the need for a higher degree of panel sealing or the addition of a drain hole, depending on the degree of sealing required for a particular vehicle. This point is discussed in more detail in paragraph 3.1.1.1. Contact resistance of terminals tested increased in varying degree. No harness or instrument panel failures occurred, except for two indicator-light failures which may have been due to an overvoltage condition caused by a faulty regulator. A great deal of mechanical trouble (not associated with the harness system) was experienced with the vehicle during the operating period, but all planned tests were accomplished.

- The use of adhesives in harness system installation met with mixed results. Two of the four types of adhesives tried were very successful, as pointedly demonstrated by the installation of the rear junction box on the fuel-cell wall with an adhesive which held so well the box had to be pried off with a crowbar. On the other hand, the attempt to install flat cable with adhesives was entirely unsuccesful.

2.4.2 Harness System Production

Prior to undertaking production of the eight (8) harness systems, the breadboard system was redesigned.

2.4.2.1 Redesign Considerations

The breadboard system was designed to incorporate as many different promising components and ideas as possible. The most satisfactory of these were chosen for the production units. Selection criteria were the laboratory test results, installation experiences, and the vehicle test performance.

2.4.2.2 Instrument Panel Redesign

In the instrument panel, two types of terminal blocks were retained; the AMP taper block in the 60-cavity configuration for wire sizes up to 16 AWG, and the Cinch-barrier block for wire sizes larger than 16 AWG. The AMP block is a nylon block with molded-in receptacles. The Cinch block is a black phenolic block with standard binding-head screws. The terminal block arrangement can be seen in Figure 5. The enclosure size was reduced from 12 inches high by 14 inches wide by 6 inches deep to 10 inches high by 12 inches wide and 5 inches deep, a volume reduction from 1008 cubic inches to 600 cubic inches.

The panel face was redesigned to improve efficiency from a human engineering standpoint. The driver's physical relationship to the panel in the M113 is such that the right side of the panel face can be seen with the least amount of head and eye movement. Therefore the panel was arranged as shown in Figure 4, with the gages and indicators oriented to the right and the switches oriented to the left.

Instead of engraving the legends on the panel front, it was decided to use mylar as a panel facing with the legends printed on it. The method used is as follows:

- The panel face is drilled and primed.
- A sheet of mylar the same size as the panel face is photographically printed on the back side with the legend.
- The back side of the mylar is painted the finish color of the panel.
- The mylar is applied to the panel face, paint side down, with adhesive.
- The holes are cut in the mylar, using the panel face as a guide.

Figure 6 illustrates the method.

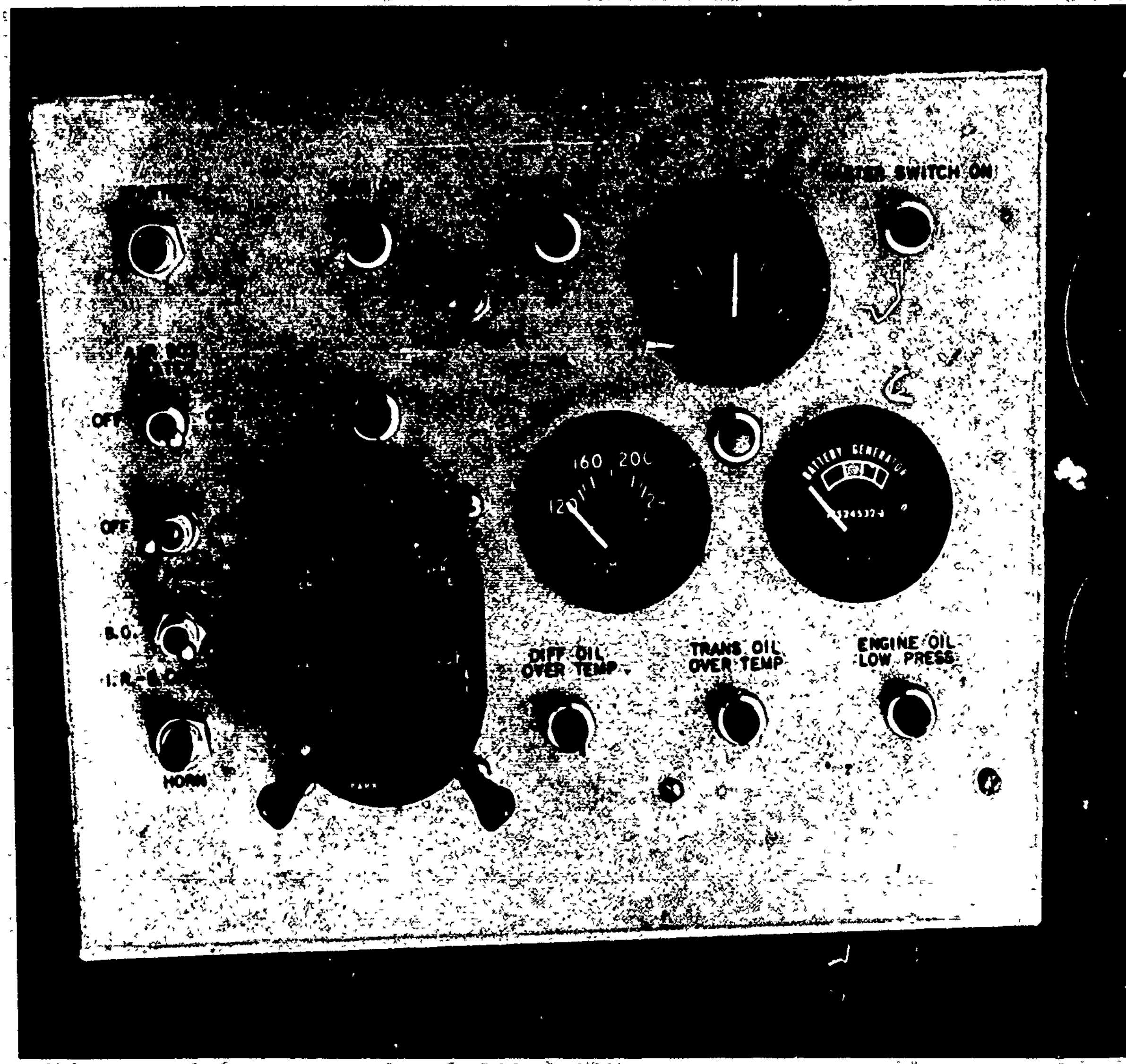

FIGURE 4 INSTRUMENT PANEL -- OUTSIDE

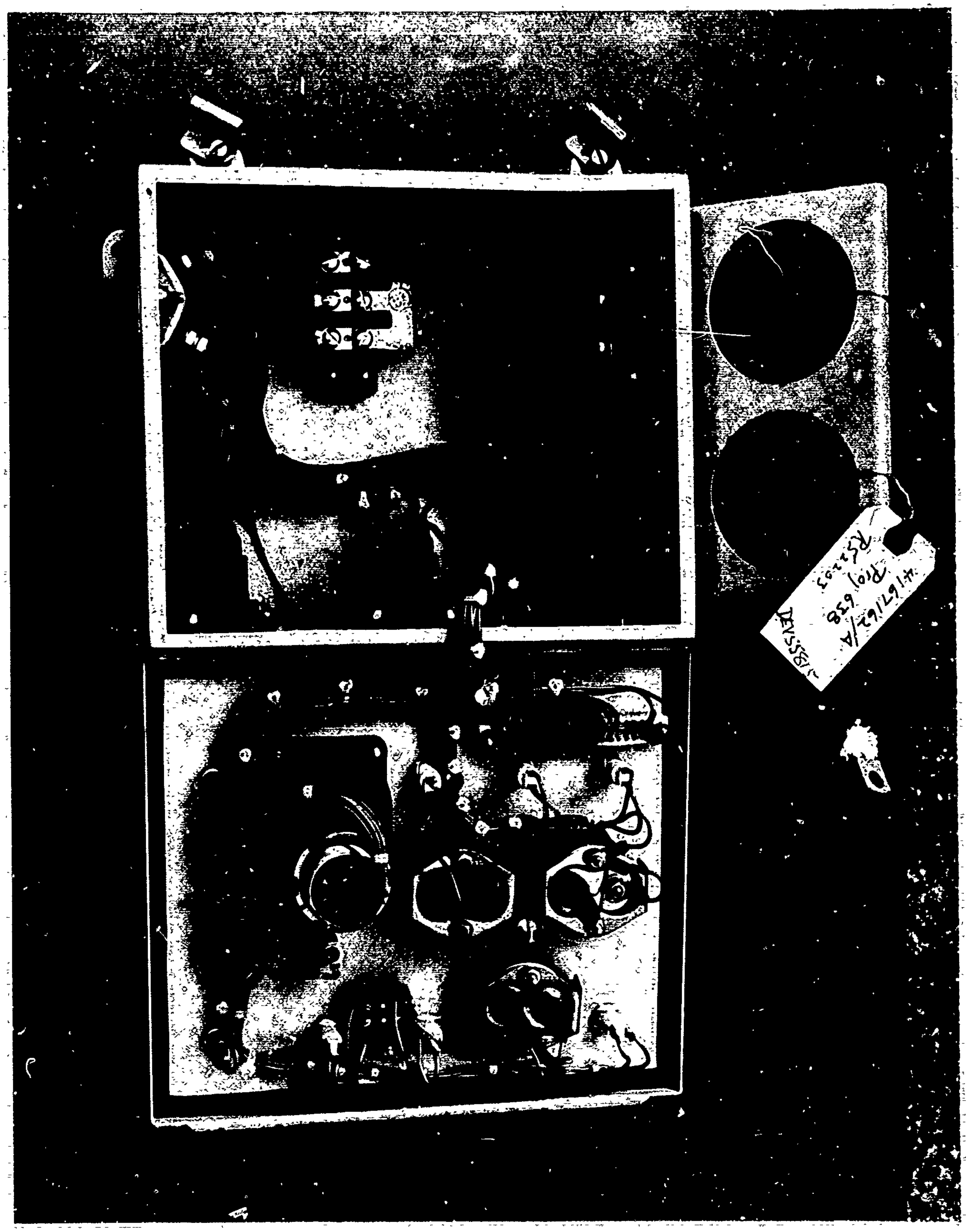

FIGURE 5 INSTRUMENT PANEL - INSIDE

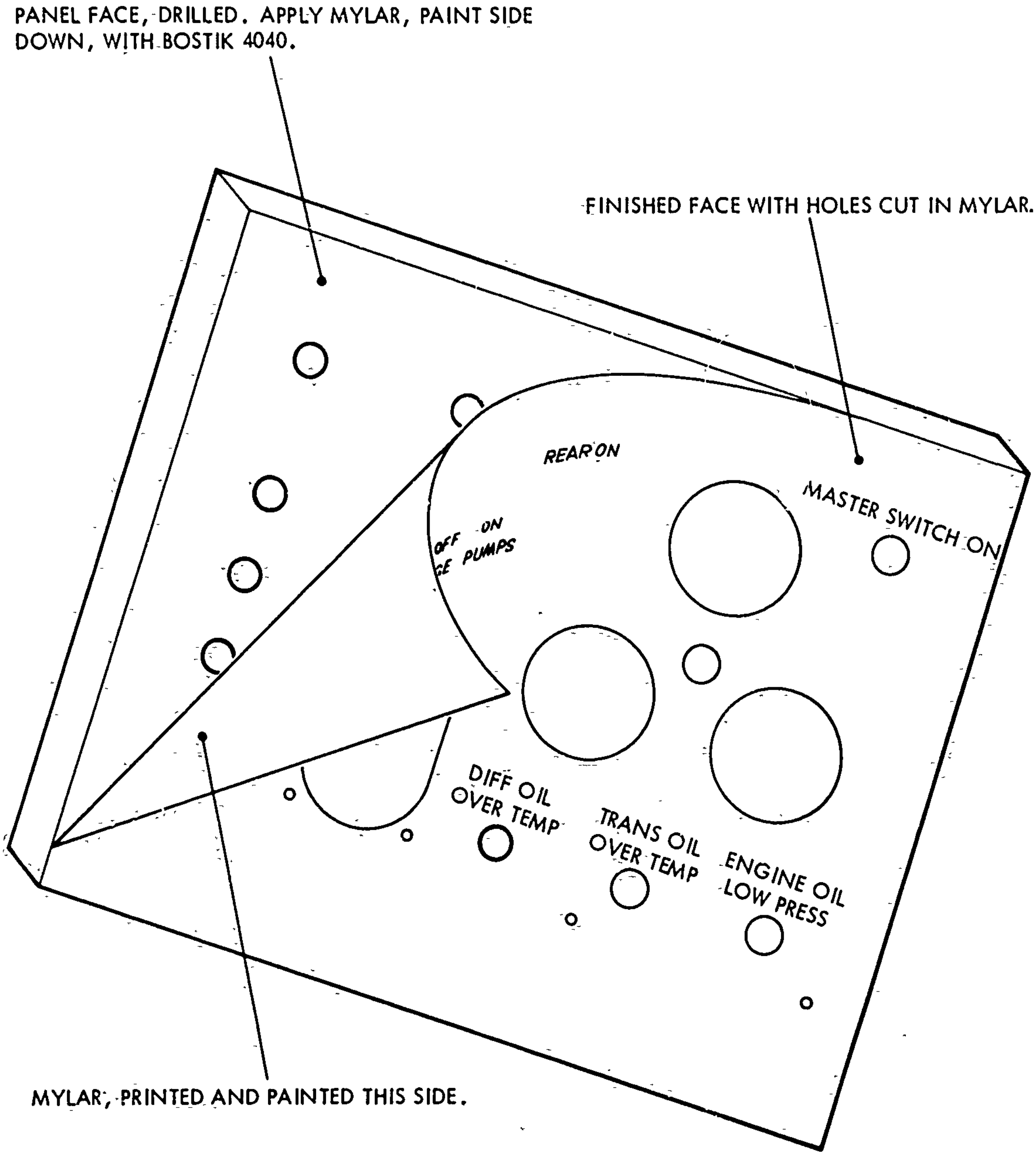

FIGURE 6 APPLICATION OF MYLAR PANEL FACING

2.4.2.3 Harness Redesign

Some of the harnesses were redesigned as a result of the tests and installation. All harnesses terminating in the instrument panel had their terminations changed to fit the terminal blocks adopted.

The harness system configuration was revised to eliminate the need for special installation hardware. Installation of the harness system can now be accomplish entirely with standard MS or commercially available parts.

Due to failure of adhesives during test program, lack of adequate connectors, and vulnerability to physical damage, the flat cable was deleted from harness system. The harnesses were made with single conductors and round, multiconductor jacketed cables. For the small size wires (14, 16 and 18 AWG) both singly and in multiconductor cables polyalkene insulation, vinylidene fluouride (Kynar) jacket per MIL-W-81044 was used. The multiconductor cable jacket was also Kynar. For the large size wires (0 and 4 AWG) .048-inch black polyurethane insulation was used.

A list of drawings developed for the production harness system is presented in Table IV.

TABLE IV

LIST OF DRAWINGS FOR PRODUCTION HARNESS SYSTEM

Drawing Number	Title
4167161	Panel Box
4167162	Panel Box Assembly
4167163	Nameplate Layout
4167164	Junction Box, Rear
4167165	Wiring Harness
4167166	Wiring Diagram, Electrical
4167167	Electrical Installation
4167168	Spacer, Support
*1067234	Bus Bar
*1067235	Bracket, Indicator
*1067243	Lead, Electrical

* These drawings were retained from prototype harness system design (Refer to Table III)

Details of harness construction are shown in Figures 7 through 12.

2.4.2.4 Production

Some difficulty was encountered in obtaining proper adhesion between the painted mylar and the panel, apparently due to chemical reaction between the adhesive and the paint. This was overcome by thoroughly drying the painted surface in an oven prior to applying the adhesive.

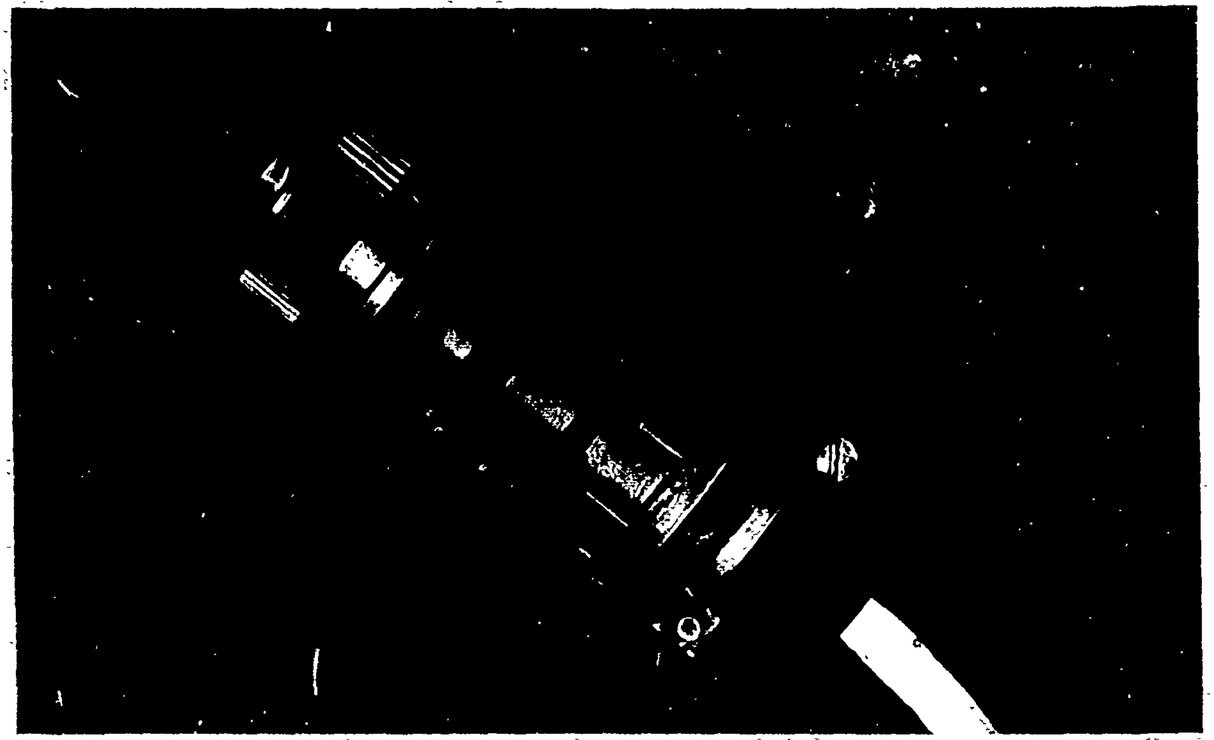

FIGURE 7 CABLE TERMINATION IN MIL-C-5015 CONNECTOR

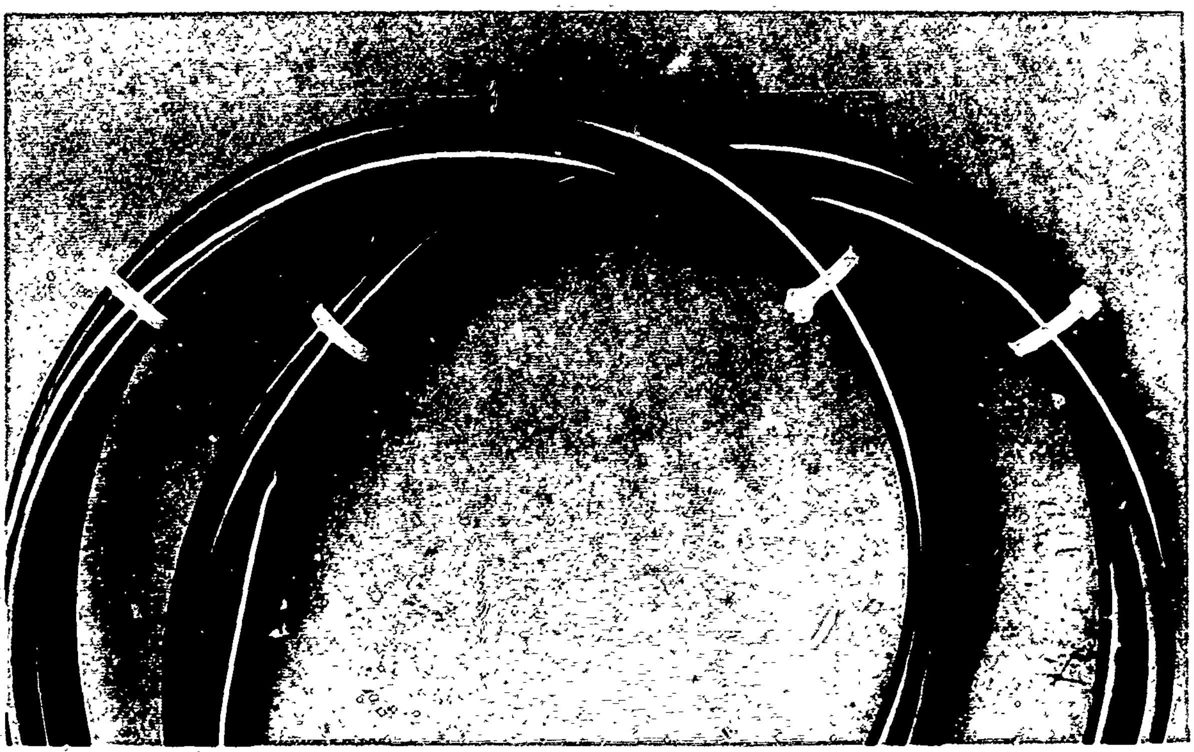

FIGURE 8 NYLON HARNESS TIES

FIGURE 9 TAPER-PIN WIRE TERMINALS

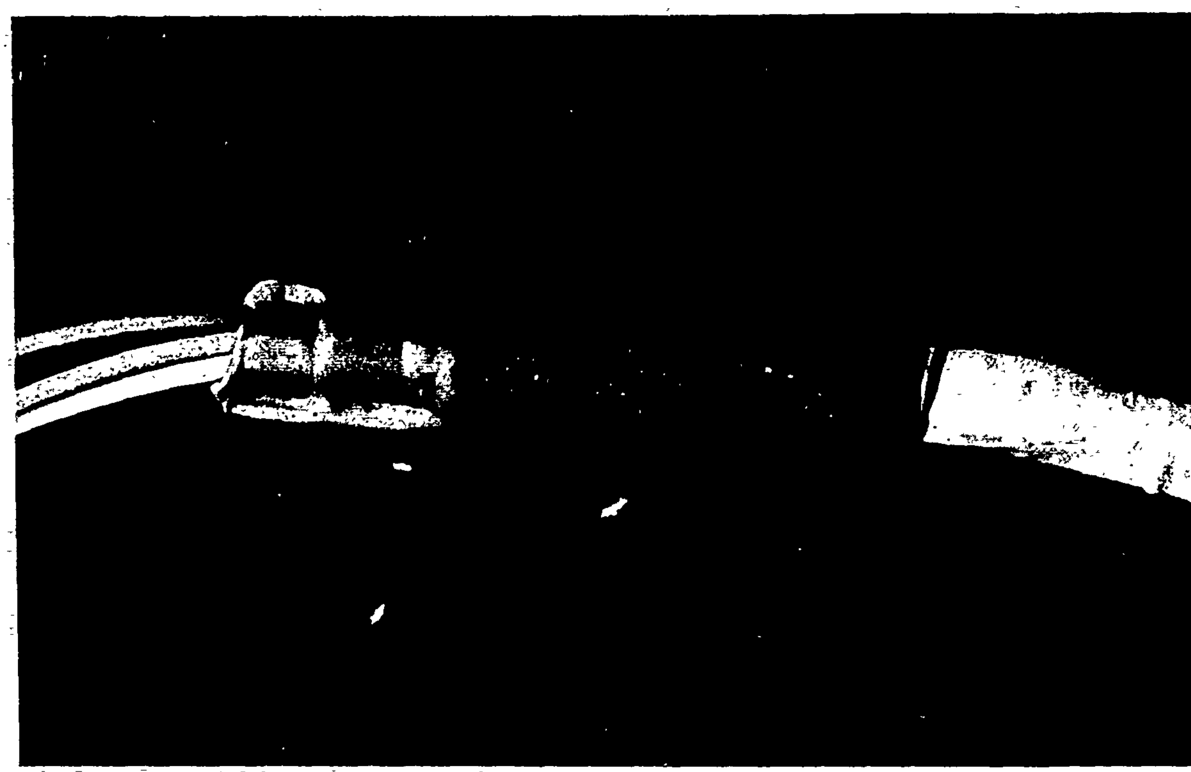

FIGURE 10 CABLE SEALING WITH TYPE SCL SHRINK TUBING

FIGURE 11 SLEEVE ADAPTER FOR SMALL-DIAMETER WIRE WITH PACKARD CONNECTOR

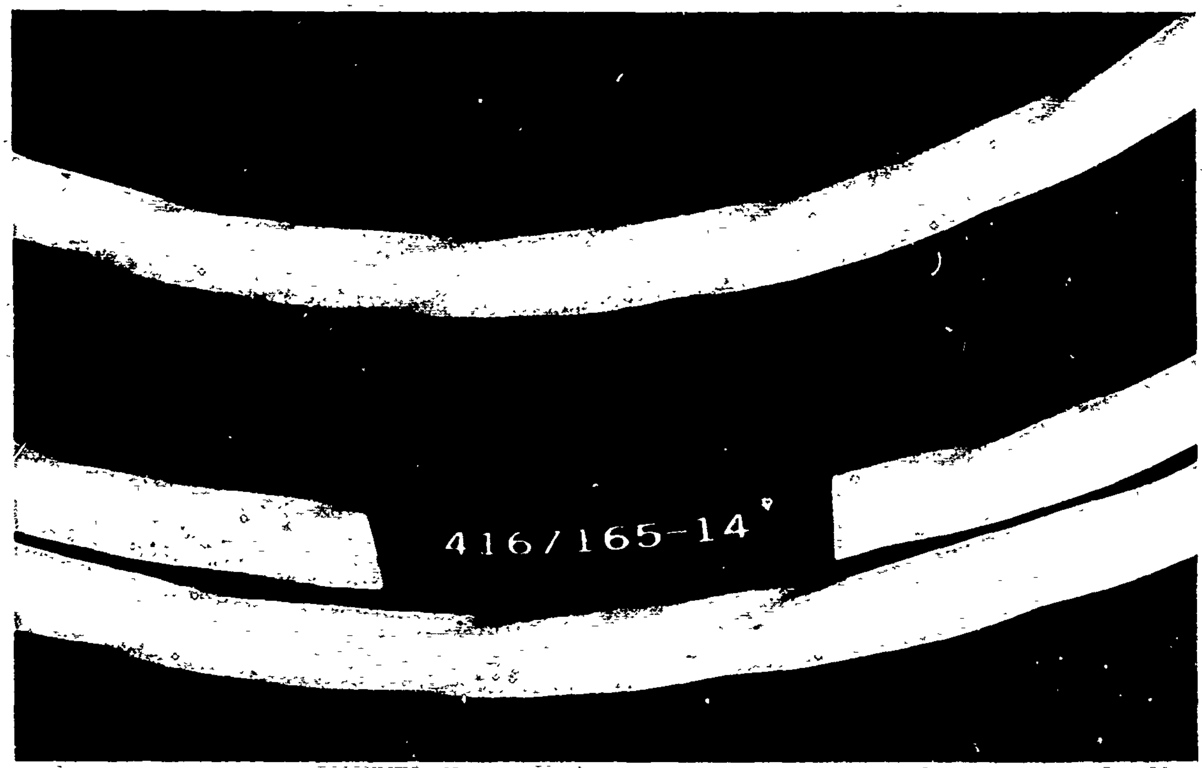

FIGURE 12 CABLE IDENTIFICATION SLEEVE

Production of the harnesses was accomplished without problem. Total production time required was 11.1 hours per system. Although this was small-quantity, prototype production in an experimental shop not equipped with high-speed production equipment, it still bettered the production-line time of over 12 hours per harness system for the M113 vehicle.

2.4.3 Typical Electric Harness Drawing

2.4.3.1 Concept

A standard drawing has been prepared, incorporating those components and methods which have been found to be the most desirable in terms of cost and suitability for use in vehicles. Notes on this drawing indicate acceptable alternative ways to construct the new harness system.

2.4.3.2 Presentation

Two sheets are sufficient for the drawing and notes. The drawing indicates an instrument panel, junction boxes, engine compartment penetrations, alternative panel and box penetrations, multiconductor cable, harnessing, and alternative methods of wire termination. The notes are of a general nature, listing the components and methods by performance required in order not to limit components to a few sources. Existing MS and ordnance terminations are shown so that the new wiring system will match existing vehicles. To preserve the moistureproof qualities of the existing MS and ordnance wire terminations when they are connected to wire with thin insulation, sleeving is shown at some of the wire entries. The enclosures are shown in outline form only, in order to limit them to application only, and not to any particular construction. So that the harness penetrations and multiconductor cables, where the jackets have been terminated in the open, will preserve their quality of being moistureproof, type SCL shrink tubing has been used as a sealant. This is a double-wall shrink tubing. Upon the application of heat, the outer wall shrinks while the inner wall mets and flows to fill the voids in the harness or to seal the multiconductor cable-jacket end.

2.4.3.3 Limits

The standard drawing is limited to the harnesses, their construction, and termination. No installation details are included. Installation, however, was a consideration of design and some of the ideas are listed:

- The present welded studs and clamps are suitable for use with the new system, but adhesive-mounted harnesses should also be included as a possibility, since it has the advantage of holding the harness closer to the bulkhead and therefore less susceptible to damage.
- Shock mounting of the instrument panel and assymetrical mounting of the panel, so that the panel face is inclined in the direction of the vehicle operator, should be considered. This arrangement is shown on Drawing No. 4167167.
- Adhesive mounting of enclosures, successfully accomplished with the breadboard system test installation in an M113, should also be considered as an installation method. While this would prevent removal of the enclosure, replacement of any individual components would of course not be hindered.

SECTION 3

FINDINGS

3.1 RESULTS AND CONCLUSIONS

The outcome of this program has been the development of a vehicle harness system that has many advantages over systems now in use. An attempt has been made to develop a system which would, as a minimum, eliminate the deficiencies of present systems which were listed in Section 2, pages 3 and 4. This was accomplished, with the exception of the harness-routing and engineering effort items which are a function of vehicle engineering rather than of harness system design. On a broader scope, an attempt was made to effect all possible improvements within limits imposed by considerations of economics, logistics, compatibility with existing equipment which must interface with the harness system, and availability of components and materials for immediate use without major development effort.

The harness system which was developed and produced for the M113A1 was generalized into a broader typical system suitable as guidance for the preparation of harness designs for any type vehicle. This sample system is shown on the drawing entitled, "Vehicle Electrical Wiring System". The basic features of the system can be divided into two categories: configuration and components. Evaluation may be divided into technical and economic considerations.

3.1.1 Configuration

The system design is built around the following features.

- A totally enclosed instrument panel as the central focus of the electrical system with the degree of sealing dependent on individual vehicle requirements. See paragraph 3.1.1.1.
- Circuitry emanating from the instrument panel either in bundled, single-conductor harnesses secured with nylon ties, or in multiconductor jacketed cable.
- Local junction boxes where required for distribution of circuits.
- Elimination of splices by use of local junction boxes or parallel conductors from source of circuit.
- Minimization of connectors by direct entry of cables or harnesses into enclosures through grommets or stuffing tubes, depending on tightness level. Bulkhead penetrations are similarly made.

3.1.1.1 Instrument Panel Design Criteria

The accumulation of condensation which was experienced in the instrument panel during the in-vehicle tests will have to be avoided if the equipment is to be suitable for the intended service. This moisture accumulation is caused by the breathing of moisture-laden air into the enclosure through the unsealed opening, and the condensation of this

moisture inside the enclosure. To prevent this moisture accumulation, three general approaches are possible; first, to prevent breathing; second, to permit breathing but prevent condensation; and third, to permit breathing and condensation but prevent accumulation.

Prevention of breathing must be accomplished by a complete sealing of enclosure openings. The panel cover-to-box interface must be completely sealed by a continuous rubber gasket. Panel instruments and controls must have sealed panel-mounting provisions and sealed faces. Cable entrances must be made through stuffing tubes per MIL-S-19622 or, where system configuration requires the use of connectors, through a watertight receptacle. This method is successfully used on shipboard open-deck electrical equipment which is subjected to severe environmental conditions.

Prevention of condensation may be accomplished by maintaining an elevated temperature inside the enclosure by use of a heating device. Although this method is commonly used in utility and industrial installations, it is not considered feasible for vehicular use since the battery drain during extended idle periods would be prohibitive.

Prevention of moisture accumulation is accomplished by permitting condensate to escape by means of drain holes.

Vehicles such as the M151 truck, which require fording capabilities, will have to have completely sealed panels, whereas swimming vehicles such as the M113 APC could have drain holes to prevent accumulation. However, experience may show that complete sealing is advantageous for all vehicles.

The instrument panel redesign and fabrication undertaken as part of this program was dictated by the need for a panel configuration compatible with the harness system. The unavailability of panel instruments and controls with the proper mounting seals, particularly the lighting switch and the gauges, precluded the possibility of a totally sealed panel. The adaptation of this harness system will require, as a minimum, design modification to the mounting arrangement and circuit termination provisions on the panel instruments. This requirement is noted in the recommendations, paragraph 3.2.3 of this report.

The effect of the total sealing concept on the cost of the instrument panel cannot be precisely determined at this time, but the factors involved can be qualitatively examined. Toggle switches, indicator lights and pushbuttons suitable for use in a sealed panel are available now in MS types at a cost less than those currently used. The lighting switch and the gauges will require panel seals, but the elimination of the connectors and rear housing (for the lighting switch) will counteract the sealing cost. A definite cost increase will be incurred with the substitution of stuffing tubes for grommets, but since the MIL-S-19622 tubes are less than a dollar each in the small sizes required, the increase in cost will obviously be small. In addition, the cover seal will result in a moderate cost increase. In total, a modest increase in the instrument panel cost will result from the total sealing.

3.1.2 Components

While specific component choices had to be made in the design and fabrication of harness systems in this program, there were, in many instances, several suitable items available for the same application. In order to keep the design choice as broad and nonrestrictive as possible, the material notes on the typical harness drawing were written to allow maximum leeway in component choice. The key component choice considerations are as follows:

3.1.2.1 Wire and Cable

A number of existing military specification wire types, and some non-specification types have the physical, electrical and mechanical properties required for vehicular harnesses. No single type can be considered best in all respects and for all applications, and the choice of the optimum type is dependent on the specific requirements of the application. An attempt to standardize on one insulation would require trade-off of properties, and therefore all, or at least a group of commonly used and suitable wire types, should be acceptable for use in harness designs within the limits of their performance capabilities. However, two insulation types which exhibit a good combination of high abrasion-resistance and physical strength, fairly high temperature rating and moderate cost, are Kynar-jacketed wire per MIL-W-81044 and polyurethane (no military specification) insulated wire. These two types are specifically listed on the typical harness drawing. A tabulation of wire insulation types is presented in Table V. All of these types have insulation materials with physical properties which will permit selection of conductor size based solely on electrical requirements.

Cable jacketing of polyurethane appears to offer the best abrasion-resistance and mechanical characteristics required in vehicles, at reasonable cost. Its main limitation is an only moderate high-temperature capability, but with careful application in engine compartments even this characteristic is adequate.

3.1.2.2 Connectors

For reasons detailed previously in this report, the only reasonable choice for multipin connectors is MIL-C-5015 Class R types, except utilizing crimp-type contacts in lieu of soldered types. Adaptors and cable clamps are available for termination of multiconductor cables.

3.1.2.3 Terminal Blocks and Terminals

On the basis of extensive tests of a number of different types of terminal blocks, the types selected as having the best characteristics are taper-pin type blocks with matching-wire terminals for wire sizes up to 16 AWG, and MIL-T-55164 terminal blocks with wire terminals per MS20659 and MS25036 for wire sizes larger than 16 AWG.

3.1.2.4 Harness Ties

Nylon self-locking tie straps per MS17821 are used for assembly of harness sections.

3.1.2.5 Panel, Bulkhead Penetrations

Penetrations through watertight panels or bulkhead are made through nylon stuffing tubes per MIL-S-19622. Interstices between individual wires of a bundle are filled by use of heat-shrinkable tubing with a meltable inner layer which, when heated, flows freely into the voids.

3.1.3 <u>Technical Advantages</u>

3.1.3.1 Reliability

Increased reliability is built into the system by (1) the more effective quality control possible with machine-manufactured and assembled items than with manually worked items, (2) the elimination of splices and soldered connections which depend on the skill

TABLE V

WIRE TYPES - INSULATION AND JACKETING*

Wire Type	Insulation	Advantages	Disadvantages
MIL-W-81044	Polyalkene with polyvinyldene flouride (Kynor) jacket	High abrasion resistance High temperature rating Good resistance to weather, chemicals and ozone.	Somewhat higher cost Very small diameter requires sleeve to maintain tightness in MS connectors.
MIL-W-5086	Polyvinyl chloride (PVC) insulation with nylon jacket	Low cost. Fairly good mechanical and physical properties.	Limited high temperature Not suitable for engine harness.
MIL-W-16878 Type BN	Polyvinyl chloride (PVC) insulation with nylon jacket	Low cost. Fairly good mechanical and physical properties.	Limited high temperature Not suitable for engine harness.
MIL-W-16878 Type E	Polytetraflouroethylene (Teflon)	Excellent temperature range. Good resistance to weather and chemicals.	High cost. Poor abrasion resistance without additional protection.
No specification	Polyurethane	Excellent resistance to abrasion, weather solvents and ozone.	Not generally available in small diameter extrusions.
No specification	Chlorosulfonated polyethylene (Hypalon)	Good resistance to abrasion, sunlight, weather, ozone. Moderately high temperature rating. Reasonable cost.	Jacket thickness requirement too large for MS connector grommets.

* Material properties shown are from Insulation Directory (5)

of the operator, (3) the reduction in connectors made possible by use of grommets or stuffing tubes with circular cross-section multiconductor cable for bulkhead penetration and equipment entry, and (4) replacement of tape wrapping by high-quality conductor covering. This increased reliability will result in less down time for the vehicle, and consequently greater effectiveness for the military unit.

3.1.3.2 Maintainability

When failures or battle damages make repairs necessary, the configuration of the new harness system facilitates the most rapid repair and return to service possible. Spare wires in the main multiconductor runs make it unnecessary to replace major sections of harness, or string and tape a new wire in case of a single open-circuited conductor. Remote sections of the harness system are replaceable without disturbance to the main runs. Panel components are more readily accessible for repair or replacement. Test points are available for testing circuits with system energized, and harness splices have been completely eliminated, thereby speeding troubleshooting procedures. This increased maintainability will not only result in quicker repairs but, in some cases, will permit specific repairs to be made at a lower maintenance echelon, reducing still further the total time a vehicle is out of service.

3.1.3.3 Longer Life

The use of the most up-to-date insulation and jacketing materials in the new harness system was dictated by the desire to lengthen the life of the harness, thereby maximizing the time between harness replacements. Past experience has shown the greatest single cause for harness replacement has been deterioration and failure of insulation and outer jacketing material. The new materials for these functions are polyalkene (tradename Kynar) and polyurethane, which, in addition to a high resistance to the deteriorating effects of weather, hydrocarbons and fungi, have the high physical strength necessary for use in military vehicles. The extended harness life resulting from these and other high-grade materials will result in longer periods between harness replacement.

3.1.3.4 Light Weight

Not normally of great consequence, this item becomes more significant for air-dropable, air-transportable, or amphibious vehicles.

3.1.3.5 Less Copper

In times of national emergency, copper invariably becomes one of the most critical of strategic materials. Our increasingly complex and electrified technology will make this even more so in the future. The conductor size reduction made possible by better insulating and jacketing materials, eliminating dependance on copper for physical strength, and results in significant copper savings when extended over the vehicle quantities built during these emergency periods.

3.1.4 <u>Economic Factors</u>

3.1.4.1 Initial Cost

As noted in the detailed report of Phase IV (4), the initial cost of an installed harness system will be approximately the same with the new system as with existing harnesses.

3.1.4.2 Repair and Replacement Cost

The data given above under Technical Advantages, fully supports the position that maintenance costs over the life of the vehicle will be reduced considerably.

3.1.5 Conclusions

The harness system developed in this program offers an immediate improvement in harness systems in military vehicles. Furthermore, this has been accomplished using, for the most part, military standard (MS) components or parts built in accordance with military specifications. The few nonmilitary items included in the system are commercial components which have been used extensively in other applications. It should not, however, be considered as the best possible system for the future, even the near future. Some component development work will be required to obtain the maximum advantages from this system. Other development programs would result in definite improvements which are now well within the state-of-the-art, but not available as hardware. Specific areas of potential development are presented in the next subsection.

3.2 RECOMMENDATIONS

3.2.1 Design Implementation

Immediate implementation of harness system design based on results of this program, as detailed on the drawing entitled, "Vehicle Electrical Wiring System", should be initiated on vehicles now in the design stage. Consideration should also be given to redesign of harness systems for existing vehicles, with retrofitting being done at normal overhaul periods.

3.2.2 Study Program

Immediate initiation of a study program for development of improved, and possibly standardized instrument panels for military vehicles. This study should include, as a minimum, the following items.

- Determination of instrument requirements from a functional and operational viewpoint
- Determination of most suitable type of instrument or control device for each function; i.e. meter vs. lamp indicator, toggle switch vs. pushbutton, etc.
- Arrangement of instruments and controls for optimum operator efficiency, based on human engineering principles
- Use of laminated or printed instrument panel wiring, as successfully used in commercial vehicles in the last several years
- Applicability of wire-welding techniques to the design and fabrication of instrument panels
- Practicality of a standard instrument panel design suitable for a wide variety of vehicles, with enough built-in variability and flexibility to accommodate the diverse needs of different vehicles, in addition to the standard panel requirements of all vehicles.

3.2.3 Design Modification Program

Immediate program to modify design of existing instrument panel equipment, or to develop new components suitable for use on an enclosed panel. The requirements include totally sealed faces; panel sealing; open terminals in rear, using terminal types common to harness system, and provision for direct electrical contact to laminated or printed wiring.

3.2.4 Panel Design Development

As an adjunct to the two previous recommendations, paragraphs 3.2.2 and 3.2.3, and depending on the outcome of those efforts, a typical or a standard instrument panel design should be developed. The drawing will complement the drawing entitled, "Vehicle Electrical Wiring System," developed during the present program.

3.2.5 Electrical System Investigation

An investigation should be made into the possible use of electrical systems other than 28 VDC. The high-power requirements of recently developed heavy vehicles such as the MBT, and the contemplated power requirements of future vehicles such as MICV-70,

warrant the adaptation of a more suitable system. Areas that should be included in this study are:

- AC System. Variable speed, constant frequency (VSCF) with inverter to supply power requirements from the battery when the engine is off; determination of optimum frequency and phase arrangement
- AC System. Random frequency operation
- Three-wire DC system with center-leg-to-chassis ground
- Hybrid systems having mixed electrical characteristics
- Determination of optimum voltage level based on economics, safety, and size and weight of equipment

3.2.6 Proposed Military Specifications

Military specifications should be prepared to cover the following items.

- Vehicle electrical harness design, based on the results of this program
- Vehicle instrument panel design
- Vehicle electrical system requirements including, as a minimum, the following items:
  (1) Circuit configuration
  (2) Application of protective devices
  (3) Transient generating limits for generators, switches, coils, etc. (referencing MIL-T-1275 as applicable)
  (4) Transient tolerance requirements for electrical equipment (referencing MIL-T-1275 as applicable)
  (5) Use of electrical systems other than 28-volt DC for general vehicle power
  (6) Use of electrical systems other than 28-volt DC for limited special use, such as electronic devices, weapon control systems, or electro optics
- Installation requirements for vehicle electrical systems.

3.2.7 Comprehensive Adhesive Study

A comprehensive study into the use of adhesives in electrical systems. In the present development program, enough success in the use of adhesive was experienced to prove that important application possibilities exist. Also, enough failure was experienced to warrant an extensive study of the subject.

3.2.8 Test, Checkout Equipment Development

Development should be undertaken of portable, automatic test and checkout equipment for vehicle electrical systems. This equipment should be usable at the lowest maintenance level. In addition to saving maintenance time requirements, it would reduce the replacement of good parts, which often occurs in the trial-and-error method of repair.

3.2.9 Flat Cable and Connector System

For future use, development of a flat cable and connector system suitable for vehicle use.

3.2.10 Illumination Study

A study should be initiated concerning vehicle illumination requirements. Applications of fiber-optics for blackout markers, taillights and instrument lighting should be included in this study, as well as the effects on lighting systems due to changes in electrical system characteristics.

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13. ABSTRACT

(U) This report covers a study and development program aimed at developing the most suitable electrical harness system for military vehicles. This program began with a broad investigation of deficiencies in present systems, the needs of future systems, and the methods and materials by which these deficiencies could be corrected and needs met. A cost analysis was conducted to determine the economic feasibility of applying these methods and materials. The study portion was followed by the preparation of a detailed system design based on the results of the study; the fabrication of a breadboard model of the system; and extensive testing of the system; including both laboratory tests of system concepts and components, and field tests with the harness system installed in a vehicle. The program concluded with the production of eight complete systems for use in the M113A1 APC and the preparation of a drawing for guidance in designing harness systems for other vehicles based on the concepts developed in this program. The result of this program is a harness system superior to present systems, and immediately applicable because only existing military and commercial hardware was used. The opportunity for further improvements exists, delayed only by the need for additional development beyond the scope of this program. Recommendations for developments efforts aimed at specific goals are included in this report.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cable						
Harness						
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Insulation						
Jacket						
Terminal						
Connector						
Splice						
Crimp						
Solder						
Adhesive						
Instrument Panel						

Security Classification